Report for 1935

Statistical Methods and Results

Rothamsted Research

responses to nitrogen in half the experiments, to phosphoric acid in one-tenth and to potash in one-fifth. Potatoes were much more responsive, significant effects being obtained in about five-sixths of the experiments with nitrogen and in one-half of those with phosphoric acid and potash.

STATISTICAL METHODS AND RESULTS
(Department of Statistics)
(a) TECHNIQUE

XXV. F. YATES. " *Incomplete Latin Squares.*" Journal of Agricultural Science, 1936, Vol. XXVI, pp. 301-315.

A description is given of the statistical procedure appropriate for the analysis of a Latin square having missing the whole of one row, one column or one treatment, or one row and one column, or either and a treatment. These are the only types of incomplete Latin squares (except those which can be dealt with by the missing plot technique), of which a neat statistical analysis is possible.

It is shown that incomplete Latin squares of these types give unbiased estimates of error and are therefore valid experimental arrangements. They are consequently likely to be of use when the experimental material is such as to preclude the use of a complete Latin square owing to the fact that numbers in one or both of the natural groups is one less than the number of treatments to be tested.

XXVI. F. YATES. " *A New Method of Arranging Variety Trials involving a Large Number of Varieties.*" Journal of Agricultural Science, 1936, Vol. XXVI, pp. 424-455.

A new method of arranging variety trials involving a large number of varieties is described. This type of arrangement, for which the name " pseudo-factorial " arrangement is proposed, enables the block size to be kept small without the use of controls.

Various possible types of pseudo-factorial arrangement are discussed in detail and the necessary formulae developed. The appropriate methods of computation are illustrated by numerical examples based on the results of a uniformity trial on orange trees. It is shown that pseudo-factorial arrangements are likely to be more efficient than arrangements involving the use of controls. In cases where there is considerable soil heterogeneity they are also markedly more efficient than randomised blocks containing all the varieties. In the chosen example gains in efficiency ranging from 26 to 57 per cent. were obtained.

XXVII. F. YATES and I. ZACOPANAY. " *The Estimation of the Efficiency of Sampling, with Special Reference to Sampling for Yield in Cereal Experiments.*" Journal of Agricultural Science, 1935, Vol. XXV, pp. 545-577.

The estimation of the yields of the individual plots of replicated experiments on cereals by sampling methods has been practised since the year 1929 at Rothamsted and its associated outside centres.

The present paper contains an investigation of the actual efficiency of the sampling processes adopted in the Rothamsted experiments, as revealed by the sampling and experimental errors. Opportunity is taken to review the theory of sampling errors and their estimation. It is shown that with a given relation between experimental and sampling variation and between the work involved in sampling and in the rest of the experiment there is an optimal percentage of sampling. It is also shown that in many cases there is little to be gained by pushing the sampling beyond certain fairly well-defined limits, even when the work involved in sampling is small.

This discussion is of importance not only in considering the application of sampling to the estimation of yield, but also in all sampling processes performed on replicated experiments. The estimation of plot yields by sampling is an application of only minor importance, since it is always possible, and often simpler, to harvest the whole of each plot ; but in many other cases sampling is a vital necessity, and results can be obtained by its aid which could otherwise only be obtained with excessive labour, or not at all. The determination of the necessary amount of sampling in such cases, and the balance between the sampling and the size of the experiment, is a problem which continuously confronts the experimenter. In particular, the individual observation of every plant, of every tree, or of every animal in an experiment, may often prove to be unnecessary when consideration is given to the amount of information obtained.

The paper also contains suggestions for certain modifications of the present sampling procedure for cereal crops. The most important of these (already employed by some workers) is the use of sampling to determine the proportion of grain to total produce on each plot, the yield of total produce being determined by full harvesting. It is shown that this method is capable of greatly reducing the sampling errors with considerably smaller samples than are at present taken, and it seems likely that the method will prove a useful alternative to the present method. The details of an efficient field technique remain to be worked out and tested in practice before it is possible to make a definite assessment of the relative advantages of the two methods.

(b) Examination of Results.

XXVIII. W. G. Cochran and D. J. Watson. *" An Experiment on Observers' Bias in the Selection of Shoot-Heights."* Empire Journal of Experimental Agriculture, 1936, Vol. IV, pp. 69-76.

In this experiment twelve observers were asked to select by eye and measure the heights of two shoots from a quarter-metre of each of 24 rows of wheat, so as to give what they considered a representative sample of the distribution of shoot heights. None of the observers' samples was found to be representative of the population sampled, and their estimates of the mean shoot height were all positively biased. This supports the evidence from other investigations that the only sure method of avoiding bias is for the sampling to be random.

The sampling process actually used in the Wheat Sampling Observations—selection of the two shoots nearest the ends of the quarter-metre—appeared to be satisfactory.

XXIX. W. G. COCHRAN. "*The Statistical Analysis of Field Counts of Diseased Plants.*" Supplement to the Journal of the Royal Statistical Society, 1936, Vol. III, pp. 49-67.

The statistical analysis of the data obtained by examining every plant in a field or green-house for disease at certain intervals is discussed. Tests of significance are given, with numerical examples, to detect (1) whether diseased plants tend to congregate in patches scattered over the area or in groups along or across the rows ; (2) whether the distribution of plants recently infected is related to that of plants previously infected ; (3) whether neighbour infection is present.

XXX. W. G. COCHRAN. "*A Note on the Influence of Rainfall on the Yield of Cereals in Relation to Manurial Treatment.*" Journal of Agricultural Science, 1935, Vol. XXV, pp. 510-522.

The study of the effect of rainfall on the yields of wheat from the continuous experiments on Broadbalk, Rothamsted, gave clear evidence of a close relation between the linear response in yield to rainfall and the manurial treatment of the soil. In later investigations of a similar nature on barley at Rothamsted and on wheat and barley at Woburn, the linear effect of rainfall on yield was not significant. This note shows that the relation between seasonal variations in yield and manurial treatment is just as clear at Woburn as on Broadbalk, the difference between the two centres being that similar studies on rainfall effects have had more definite and successful results on Broadbalk. At Woburn, indeed, little progress has been made towards elucidating the particular weather factors whose quantitative influence is important.

For both barley at Woburn and wheat at Rothamsted, which were the cases examined in detail, the grouping of yields according to manurial treatment remained after eliminating the effect of the significant weather factors which were found. This shows that at both centres there are influences, other than rainfall effects of the type examined, whose effect on the seasonal variations in yield is closely associated with manurial treatment.

Some discussion is given of the appropriate test of significance of the difference between two rainfall curves and of a somewhat analogous case which arises in the interpretation of the results of a series of replicated experiments at different centres.

XXXI. M. M. BARNARD. "*An Examination of the Sampling Observations of Wheat of the Crop-Weather Scheme.*" Journal of Agricultural Science, 1936, Vol. XXVI, pp. 456-487.

Sampling observations are now being taken at ten British agricultural stations on each of two standard varieties of wheat. These observations form part of the Crop-Weather scheme spon-

sored by the Ministry of Agriculture and Fisheries and the Meteorological Office, and their function is to provide information on the influence of meteorological conditions on all stages of the wheat crop's growth from germination to harvest. They also supply information on the connections existing between the different stages of the crop's growth.

The present paper describes a preliminary investigation of the results of the first three years, 1933, 1934 and 1935. The following points have been investigated : (*a*) the length of the interval from the time when the crop is sown until it appears above ground ; (*b*) the date at which the crop has twice as many tillers as plants and the rate at which this tillering occurs ; (*c*) the maximum number of shoots formed per unit length of drill row ; (*d*) the maximum rate of increase of shoot height ; (*e*) the yield of grain per acre.

Associations have been found to exist between each one of these quantities, and either specific meteorological factors, or earlier measurements of the crop's progress. In some cases both types of association occur. In the case of the yield of grain, no association with meteorological factors has manifested itself. It would appear, therefore, that such relations are likely to be complex and must await further data for their elucidation.

During the last three years a close connection was found to exist between the yield and the shoot height at ear emergence, greater yields being associated with taller crops. It is probable, therefore, that measurements of the crop's growth, possibly in conjunction with meteorological measurements, will give more reliable predictions of the yield than those obtained from the latter alone. The practical application of this aspect of the results is discussed in Paper No. XXXII below.

XXXII. F. YATES. "*Crop Estimation and Forecasting : Indications on the Sampling Observations on Wheat.*" Journal of the Ministry of Agriculture, 1936, Vol. XLIII, pp. 156-162.

The estimation of the yields of agricultural crops, and the forecasting of such yields before harvest, are problems of considerable importance in agriculture, especially since the introduction of a measure of control in agricultural production and marketing. The present paper discusses the forecasting of the yield of the commercial wheat crop about six weeks before harvest by means of simple measurements on the growing crop.

That this is a possibility is indicated by the results of the first three years of the sampling observations on wheat, which were taken at ten stations under the Agricultural Meteorological Scheme. These revealed a very close connection between shoot height at ear emergence and final yield of grain. There was also a slight negative correlation with plant number.

The problem of estimating the yields of commercial crops at harvest by sampling the standing crops is also discussed. Some trial sampling of this type was undertaken by the observers of the Agricultural Meteorological Scheme.